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The DESS Model

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A Detailed Energy System Simulation Model for the EC Countries

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Abstract. The DESS (Detailed Energy System Simulation) Model is a tool for translating energy demand forecasts into their economic and environmental consequences. This model, which has been used for the Danish national energy planning, was developed and extended within the energy modelling program of the Commission of the European Communities into one that is able to simulate different national energy supply systems, in particular the power generating and space heating sectors. The model has now been implemented for Denmark, Germany, and Italy. The model implementation is described in this report, and further applications of the model is discussed. These include: national or multinational database and simulation model for the energy system, database and preprocessor for optimisation models, and sectoral models, in particular for the power system with combined heat and power (CHP). Finally, the use of simulation models and optimisation models, e.g. the Energy Flow Optimisation (EFOM) model, is discussed.

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Contents

Preface

This is the final report of the project »Energy system simulation model for the EC countries (The DESS-Model)« according to contract no. EN3M-0022-DK (B) with the Commission of the European Communities. It summarises the work and deliverables that have been made during the contract period from 1 October 1985 until 31 December 1988.

A detailed description of the model with tentative results and a User's Guide for the software was submitted to the Commission as a Status Report in September 1987. An update of the results was submitted in a final report for the contract period until the end of 1987 in June 1988. A software package in versions for Digital VAX and IBM Computers was submitted in October 1988, and a revised release of this software and the User's Guide was submitted in February 1989.

Part of the work has been done in collaboration with institutions in Germany and Italy. We would like to thank Professor Ulf Hansen and Mr. Harry Pospischill, University of Essen, Germany, Professor Giancarlo Pinchera and Mr. Willy Bocola, ENEA, Rome, Professor Giancarlo Clerici and Mr. Amilcare Tanzi, ARS S.p.a., Milano, Italy; and from the CEC, DG XII, Brussels, Dr. Frans van Scheepen and Mr. Claude Thonet, for their contribution to the data collection and model implementation.

The work was carried out by a project group from the Systems Analysis Department with Poul Erik Grohnheit as project leader, and Peter Skjerk Christensen, Kirsten Halsnæs, and Henrik Sørensen. The group has visited the participating and other institutions in Germany and Italy for model implementation and data collection., and seminars were held by ENEA and ARS S.p.a. in Rome in June 1988 and by Risø in October 1988. During March and April 1988, Poul Erik Grohnheit visited Science Policy Research Unit (SPRU), University of Sussex, Brighton, UK. Chapter 6 in this report is based on studies during this stay. The EFOM model was implemented by Ole Gravgård Pedersen on Risø's Digital VAX computer under EC contract no. EN3M-0044-DK (B).

The implementation of the model for Italy has been published by Risø as a separate report by Kirsten Halsnæs and Henrik Sørensen (Risø-M-2798), which is available on request from Risø Library. The User's Guide by Peter Skjerk Christensen and the DESS software package is available on request from the Systems Analysis Department, Risø National Laboratory.

A selection of reports concerning the DESS Model and publications for which the model has been used is listed in the Selected Bibliography at the end of this report.

1. Introduction

The overall purpose of the DESS (Detailed Energy System Simulation) Model is to provide a flexible and easily understandable tool for translating energy demand forecasts into their economic and environmental consequences. This model has been used since the early 80s as the most comprehensive one for the Danish national energy planning as well as for various partial studies of the Danish energy system.

1.1. The EC Project

The idea of the DESS Model was taken up within the energy modelling program of the Commission, and a project was started in 1985 to develop and extend the model that was used in Denmark into one that is able to simulate different national energy supply systems, in particular the power generating and space heating sectors. This model has now been implemented for Denmark, the Federal Republic of Germany, and Italy.

The implementation for Germany was carried out in cooperation with the University of Essen. It describes the structure of the German power system with emphasis on the prospects for combined heat and power. The implementation for Italy was carried out by Risø, focusing on the heat demands in various climatic regions and the simulation of a power system containing both hydro and thermal generation.

A software package has been developed at Risø's VAX 8700 computer, and the portability to IBM and other computers has been demonstrated.

1.2. The Model Framework of the DESS Model

The DESS Model is an accountancy model in which mainly simple calculations are made. The model may, therefore, be very data-intensive, and, thus, well suited as a database for models that are mathematically more complicated. These models, however, require data that are very well-selected and well-examined. The DESS Model has been used for that purpose for the Danish contribution to the Energy and Environment study of the DG XII, which uses the Energy Flow Optimisation Model (EFOM).

While econometric models, e.g. the HERMES or MIDAS Models of the CEC DG XII energy model system, are used to produce forecasts of the demand for useful energy or energy demand carriers, the supply side may be modelled using simulation or optimisation models.

Like the EFOM Model, the DESS Model is demand-driven, thus requiring as input a forecast of a demand vector. The purpose of the model is to investigate the consequences of a range of technology choices, forecast assumptions, and investment sequences. Both economic and environmental consequences may be analysed.

In the general description of the DESS Model, an energy balance of supply and demand is disaggregated to an appropriate number of conversion and end-use technologies, for which the capacities are subject to forecasts. When available technologies are competing, the model may be allowed to use them in »merit order«, e.g. according to their variable costs. For this purpose the model also includes a facility for the power system with CHP, simulating the economic dispatch of electricity loads on the basis of seasonal load duration curves and a merit order of power generation units.

1.3. The Energy Flow Optimisation (EFOM) Model

In the Energy Flow Optimisation (EFOM) Model, the energy supply system is described as a network of energy conversion, transport, and end-use facilities. A linear programming problem is set up and solved in order to disclose an optimal solution for the sequence of investment in energy conversion and end-use technologies as well as emission abatement measures.

The EFOM Model is the supply part of the Commission's energy model complex, which has been used since the 70s. An extension of the model that includes emissions of pollutants as well as emission abatement techniques was developed by three German institutes during 1986 and 1987 as a part of the research project »Optimal Control Strategies for Reducing Emissions from Energy Production and Energy Use on an European Level« [1]. This model has now been implemented for all EC countries, and various scenarios for the reduction of pollutants - in particular SO_2 and NO_x - have been studied.

1.4. Applications of the DESS Model

There are several applications for the DESS Model. Those included in the present study are the following:

- National database and simulation model for the energy system
- Multinational database and simulation model for the energy system
- Database and preprocessor for optimisation models, e.g. EFOM
- Sectoral model, in particular for the power system with CHP

1.4.1. National database and simulation model for the energy system

As mentioned above, the DESS Model has been used in Denmark for national energy planning. Forecasts for the demand sectors were calculated by other models, and exogenous development plans for the energy conversion and end-use sectors were brought together in the DESS Model in order to calculate the annual primary energy requirements, energy system costs, and emissions of SO_2 and NO_x. A detailed description of this application is found in Grohnheit (1986). A proposal for a similar application for Italy is described in the report by Halsnæs and Sørensen (1989).

1.4.2. Multinational Database and Simulation Model for the Energy System

The basis for this type of simulation model is a multinational energy balance, e.g. the one produced by Eurostat. In the DESS Model, the energy balance of supply and demand is broken down to an appropriate selection of conversion and end-use technologies for which forecasts are made. This application of the model is described in Chapter 4.

1.4.3. Database and Preprocessor for an Optimisation Model

The EFOM Model - and most other mathematical optimisation models - make use of a very purpose-specific database. For this reason, the preparation of data for these models demands some kind of preprocessing of national specific data, e.g. data for demands, capacities, prices, etc. As a more general database, the DESS Model may be used for this purpose.

1.4.4. The Power System with CHP

The DESS Model may also be used for sectoral studies. For many of these purposes, other models or commercial software may be more adequate if CHP plants are not included. However, if CHP is included, the DESS Model is a unique tool. A detailed description of the use of this model feature and its application is found in Grohnheit (1986) and in Grohnheit and Laut (1987). An implementation for Germany is described by Pospischill (1987). In Chapter 6, an example of a study of CHP in densely built urban areas is scheduled, using both the DESS and EFOM models.

2. The Model

The DESS model describes a system of energy conversion units that connects the demands for various types of useful energy to the requirements for various types of fuels.

Given a set of forecasts for the demand for useful energy, energy prices, and the development of the conversion and distribution system, the model produces detailed results of the structure of the future energy supply system including primary energy requirements, energy system costs, and selected environmental consequences. The results may be presented as a time series covering a long period, or as different alternatives to a reference scenario for a future year.

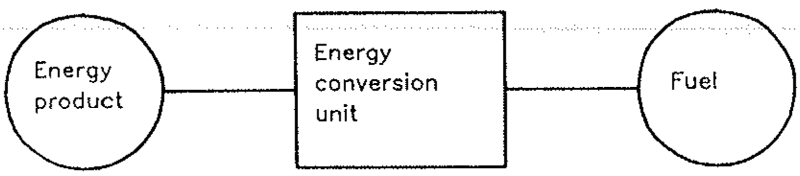
It is an important feature of the energy system that most types of energy demand can be satisfied from several sources. For such competing conversion units, a merit order is specified by the model or the user which leaves some types of conversion units as residuals. The calculated productions from these residual conversion units are essential for evaluating the feasibility and acceptability of the simulation results.

The power system with CHP is the most important subsystem of competing units. The variation in the power demand is described by load duration curves, and the generating units are scheduled in merit order according to their variable costs, enabling the fuel requirements to be calculated.

2.1. Energy Conversion Units and Efficiencies

The energy conversion units in the DESS Model may be types of power stations, district heating plants, transmission and distribution grids, or typical heating systems for buildings. The principle is shown in Fig. 2.1; the information flow goes from left to right, the physical flow from right to left.

Fig. 2.1. Energy conversion unit



Each of these elements is described by:

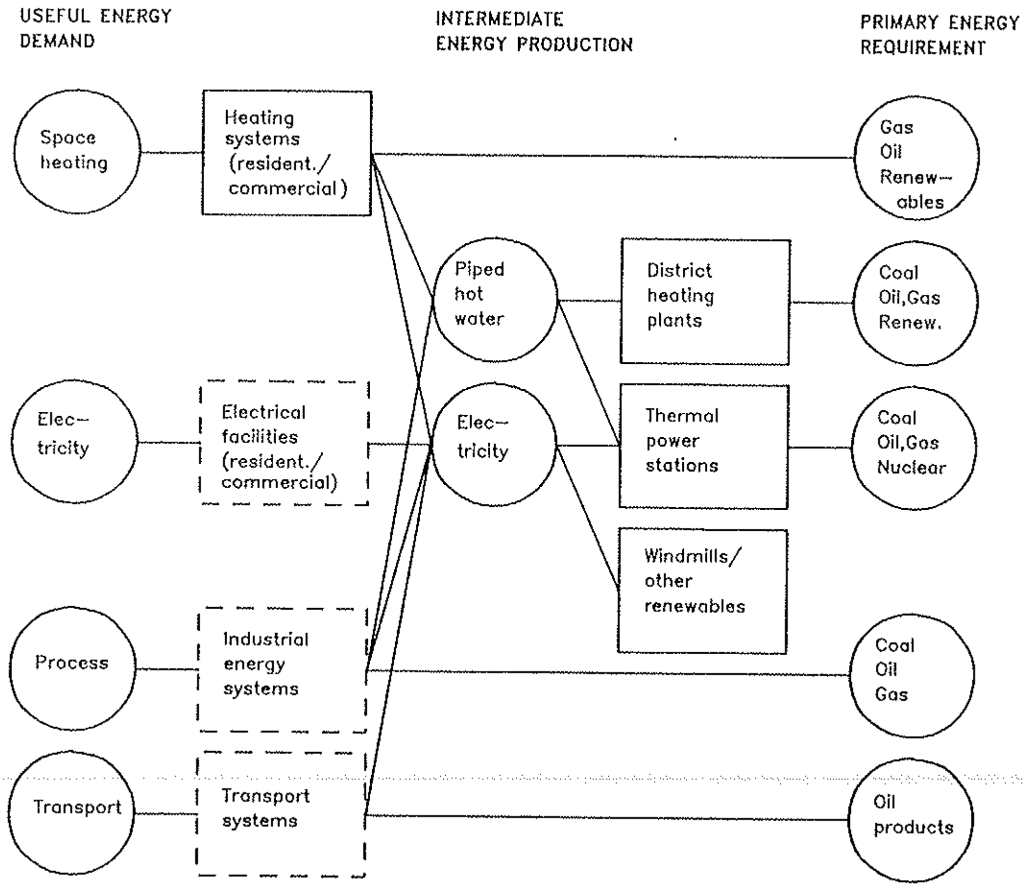
- type of energy output
- type of energy input
- capacity
- efficiency, i.e. output per unit input
- investment costs
- annual operating costs
- emission factors for pollutants

A network of energy conversion units is built up consisting of the most important categories of conversion units and the most important energy flows between the demands for useful energy, intermediate energy products, and primary energy requirements. This is illustrated in Fig. 2.2 for the Danish energy system.

The following calculations are made for a typical element in this network:

Flow out	=	Number * Unit capacity * Unit flow
Flow in	=	Flow out / Efficiency
Operating cost	=	Number of units * Unit cost
Investment cost	=	Number of new units * Unit cost
Emissions	=	Energy inflow * Emission factor

Fig. 2.2. The energy flows of the DESS Model



For residual elements:

	Number	= Total – Competing installations
or		
	Flow	= Total flow – Flow of competing element

For power stations:

Submodel based on load duration curves and merit order of units

For sectoral modules and the total model:

Fuel costs = Fuel flow * Fuel prices
Summing up flows, costs, and emissions

2.2. The Power System with CHP

The simulation of the electricity and heat supply from thermal power stations is the most elaborate part of the DESS Model. This simulation is based on the following features:

- Each generating unit or type of units is described by simplified data: maximum electricity and heat output, fuel type, fuel requirements for start-ups, efficiencies (heat rates) for condensing and back-pressure (CHP) generating modes, power per unit heat at back-pressure mode, types of pollution abatement facilities, availability, reliability, operating and maintenance costs,
- the variation in the annual electricity demand is described by load duration curves for up to 12 periods,
- the heat demands in each CHP-region are specified as the average demand in each period that is specified by a load duration curve,
- the annual electricity demand within the power system is specified by the maximum load demand and the load factor, and
- fuel prices are specified for each fuel type.

The annual demands of heat and power are satisfied in the most economical way using the following principles of load dispatching:

- The maximum power of each unit is corrected for unavailability, i.e. maintenance and breakdown.
- A priority list is set up according to the variable costs (merit order). Extraction units are divided into back-pressure and condensing parts and placed at the appropriate positions in the merit order, taking into account benefits arising from cogeneration.
- The units are placed under the load duration curve as bands from the bottom according to the priority list, as shown in Fig. 2.3.

The results of the simulation will be the annual electricity and heat output for each unit or type of units, and the fuel and operating costs of these units. These results are aggregated into groups of units characterized by fuel type, CHP supply, flue gas desulphurisation (FGD) facilities, etc.

The annual production from wind turbines is calculated from an estimate of their number and unit production. The demand for power from thermal stations is reduced accordingly, and the load duration curve is modified.

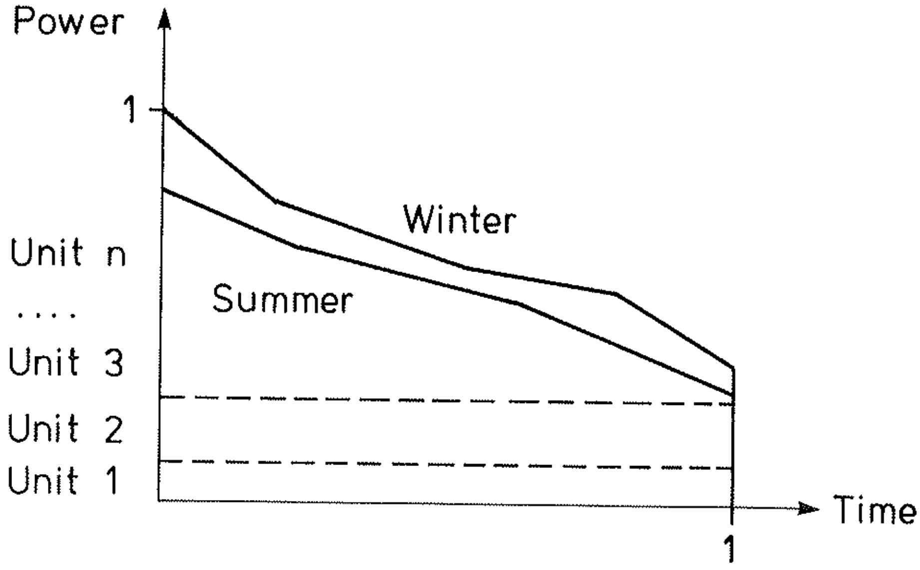


Fig. 2.3. Load duration curves for the electricity generating system for two periods (winter and summer).

Hydro power, which does not exist in Denmark, may be treated in the same way.

In countries, e.g. Italy, where hydro power is an important part of the electricity supply system, a more elaborate study will be necessary. For this reason, the Italian power was described within this project using monthly load duration curves (Halsnæs and Sørensen, 1989).

The model can simulate a power generating system consisting of many different type of units. This is important for an accurate simulation for national or regional planning purpose of conditions in the near future, when the mix of unit sizes and efficiencies is well known. For an international model, or when simulating conditions in a more distant future, a more simplified model of the system is preferred using technical data for only a few types of units.

2.3. Model Structure and Data Requirements

The DESS Model for a country or region is composed of modules for energy subsystems with suitable interface variables; each module consists of energy data and submodels of varying complexity, ranging from simple accountancy assignments to the simulation model for the electricity generating system with CHP. These elements are organised into logical units, or »phases«, which may be calculated separately for all years or in line with other phases. All kinds of data are organised into »accounts«, which are time series of maximum 40 years. Each account is identified by an 8-character two-level alphanumeric number and a short text. Groups of accounts may thus be treated as vectors, and vectors are organised using the identification systematically. The techniques of the model are described in detail in the User's Manual.

A common model structure has been built up, which can describe the energy systems for different countries at various levels of detail. This model structure covers the national energy system, which is supplied by fuels that are internationally traded, i.e. coal, oil products, nuclear fuel, etc. In addition to this main model structure, which is illustrated in Fig. 2.2, additional modules may be added, e.g. the refinery sector, thus adding crude oil to the list of fuels.

A survey of the data requirements for the main model structure is found in Table 2.1.

An easy and operative way of making the national energy system complete is to put the various model modules into a framework of a well-established energy balance. If the energy balance is taken from international statistics, e.g. Eurostat [2] or the annual IEA energy balances [3], this procedure will yield internationally comparable results, and at the same time enable the analyst to focus on those parts of the various national energy systems that are interesting for the particular study. This application is described in Chapter 4, below, together with a more detailed description of the structure of model phases and variable identifications.

Table 2.1. Data requirements for the main model structure

Overall data	Fuel prices Inflation rates Initial energy balance
Building data	Building areas Unit space heating demand Dwelling sizes
Renewables/Small conversion units	Number of units Technical data (electricity or heat loads, utilization times, efficiencies, specific substitution, etc.). Investment and operating costs per unit.
Heat installations	Number of units Efficiencies Lifetimes, investment and operating costs
Process energy	Fuel demand from an econometric model Planned fuel consumption (e.g. natural gas, indigenous coal)
Transport energy	Fuel demand
Electricity and CHP system	Technical data (load, availability, efficiency, operating costs, etc.) for power generating units Load duration curves for electricity Development plan for new power units Investment costs for new power units Pay rates for new power units Total electricity demand Heat demand from CHP stations in heat regions Distribution of heat demand into time periods
District heating	Fuels for district heating

In addition to the main model structure, several modules for further consequence analyses have been developed. These include: a module in which the primary fuel requirements and energy system costs are assigned to the various demand sectors, i.e. space heating, process, transport, and misc. electricity; an emission module in which emissions of SO_2, NO_x, etc. are calculated and assigned to various supply or demand sectors; and a module in which the energy balance for the annual IEA reports has been set up.

2.4. Software and Computer Requirements

The software which is used to implement and run a model on a computer is called the DESS System. It is now written in FORTRAN 77 with comments in English, and has been in a state of on-going development during the last decade. The intense use of the model has led to the development of a variety of new features and improvements.

The DESS System contains facilities to:

- declare and describe variables and vectors,
- formulate arithmetic equations using simple variables and vectors,
- include special functions carrying out processes which either are used very often or cannot be described by simple arithmetic expressions,
- process the equations formulated above over a number of years, maximum 40,
- present the results in tables or line printer plots
- store and retrieve data from permanent files,
- point out errors in the input stream or the processes.

The present FORTRAN 77 version of the software has been developed and tested at Risø's Burroughs B7800 and Apollo Domain 3000, IBM computers at UNI.C, Lyngby, Denmark and Hochschulrechenzentrum, Universität Essen, Germany. The model development was then moved to Risø's Digital VAX 8700.

The present software package of the DESS System, Release 1.4 from February 1989, consists of source files for VAX and IBM Computers, an executable file for the VAX, an online manual, and test and demonstration files. The total size of these files is 2 Mbytes, which is available on two floppy disks (Christensen and Grohnheit 1989). The system and test examples are described in the User's Guide (Christensen 1989). The portability of the executable file in other VAXs has been demonstrated, and the IBM Version has been implemented successfully on the IBM 4341 at the University of Essen (Pospischill 1988).

It may be argued that a special purpose FORTRAN program for different mainframe computers is obsolete compared to the commercial database and spreadsheet software for personal computers that are now available. Most parts of the structure of the DESS Model can easily be implemented using commercial spreadsheet software, e.g. Lotus 1-2-3, which has already been used as a post-processor for DESS results for presentation of results or transfer of data between DESS and other model systems, in particular EFOM.

However, the power system part of the DESS Model requires a special purpose software, and most commercial spreadsheet software for PCs is not easily able to handle large amount of data and long series of calculations. Transferring the model to a more modern and user-friendly software would require the selection of the appropriate software and transfer of the model, which is very time-consuming. The existing DESS software is portable and well documented, and data and results can be transferred to other systems when needed.

3. National Application

The DESS Model has been used in Denmark in a number of versions for a variety of scenarios. Part of the model was originally developed by the Danish electrical utility ELKRAFT in the early 70s and named Long-term Planning System. The purpose of this model was to simulate the operation of a system of power stations that includes Combined Heat and Power Generation (CHP), together with calculations of the running costs. It was redesigned and extended by Risø for use in a study of electrical heating by adding a module that calculates the economic consequences of the demand for space heating produced by CHP, natural gas, or electrical heating. Further extensions include a module for calculating the emissions of SO_2, NO_x, CO_2, CO, particles, etc., and a module for setting up the energy balance for the IEA Annual Reviews [4].

This model (Danish Energy System (DES) Model) was used as the most comprehensive one for the Danish energy planning. This includes the use of the model for evaluating the different scenarios described in the Energy Plan 81, the scenarios for the Status Reports from the Ministry of Energy in the following years. The model has also been used for several partial studies of the energy system, e.g. the economic assessment of nuclear power, the environmental consequences of energy system changes, and scenarios for long-term consequences of the technological development. (Energiministeriet 1984, Christensen et al. 1984, Grohnheit 1984, 1986b, Grohnheit et al. 1987a,b, Grohnheit and Laut 1987).

3.1. Denmark - National Energy Planning

The model structure that was developed during the project for the CEC and used by Risø for the calculations made for the 1986 and 1987 Status Reports is described in detail in this section.

3.1.1. Space Heating

The space heating sector includes the demand for space heating and domestic hot water in all buildings except those for industrial and agricultural production; the heat demand for the latter is included in process energy.

The demand is calculated as the product of building areas and useful energy demand per m^2. Forecasts are made for single and multi-family houses, commercial buildings, hospitals, etc. built before and after 1980. The data for building areas by kinds and uses are supplied from the central Building and Dwelling Register. The future building areas are found by reducing the existing building stock by projected demolishing. Forecasts of new building areas are based on assumptions on economic growth and demographic development in the planning period.

3.1.2. Small Conversion Units

Some of the most important energy conversion units for the recent Danish energy planning outside the power system are renewables and other heat installations for space heating.

Renewable energy installations are designed to produce electricity or heat for space heating. Straw furnaces and biogas plants may also produce heat for, e.g. grain-drying or heating of agricultural production buildings, which is considered as process energy. There is a strong political commitment for a substantial penetration of renewables and indigenous fuels (straw, wood, etc.) in areas not supplied by natural gas, CHP, or industrial excess heat.

Other heat installations include electrical heating systems, oil and gas furnaces, and house installations for district heating, as well as fossil-fueled district heating plants.

In Denmark, about half the building area is in one-family houses, and for each of these houses there is a heat installation. The main task of the Heat Planning Act was to replace oil furnaces with natural gas furnaces or district heating. This has had a substantial effect on the projected demand for fuel (Grohnheit 1986b).

3.1.3. Process Energy

Process energy in the DESS Model includes the demand for fuels, electricity, and district heating in industry, agriculture and forestry, horticulture, fishery, and construction. The definition of process energy includes on-site transport and space heating of buildings for production.

In the version of the model developed for the Danish Ministry of Energy, forecasts for process energy demand has been made by econometric methods for four types of fuels: solid, fluid, electricity, and transport fuels [5]. No general useful energy concept is defined for process energy. The only calculations that are made within the model for process energy other than electricity are the substitution of natural gas, district heating, and renewables for solid and fluid fuels as well as splitting fluid fuels into oil products according to some aggregate parameters.

3.1.4. Transport Energy

Like process energy demand, no useful energy concept is defined for transport energy, so the transport energy demand is described by the demands for transport fuels and electricity for transportation. The transport energy demand is divided into the subsectors: persons, goods, and other transport, the latter including international air traffic and defence. The energy demands for agriculture, fishery, and internal transport are included in the process energy demand. Foreign bunkering is not included in the national energy demand.

3.1.5. The Power System

The load variations of electricity and heat in the Danish model version are described by load duration curves for two periods during the year.

In a more detailed model (Larsen 1984) [6], the load dispatch among the available units can be simulated for a number of periods with different demand variations for electricity and heat given by two-hour time steps. It has been shown that the load variations during two 3-day periods around the equinoxes can be used for a reasonable simulation of the whole year (Grohnheit 1986a). The corresponding load duration curves based on these data are shown in Fig. 3.1.

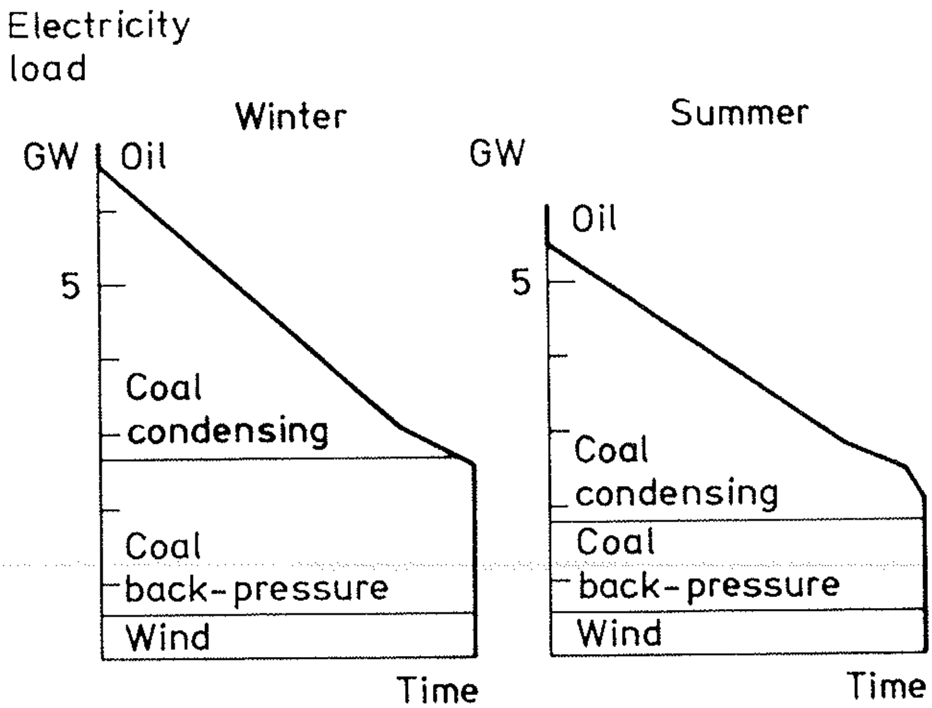
The projected electricity demand will correspond to a maximum load (winter peak) of 6.9 GW. The projected heat demand from CHP for the winter season will correspond to an average back-pressure power load of 2.1 GW. For simplicity, back-pressure production is modelled as a constant load during each half-year. Wind power is shown as a constant average load of 0.6 GW, and electricity trade is not taken into account. The structure of the demand for heat from CHP is described by three types of heat regions: the Copenhagen Region, five city regions (Odense, Aarhus, Aalborg, Esbjerg, and the Skaerbaek Region), and several smaller towns. The Copenhagen and other city regions are supplied mainly by large extraction plants, each in the 200-400 MW range. There may, however, be some older and smaller CHP units in these heat regions. The smaller CHP towns will be supplied mainly by back-pressure units between 10 and 90 MW designed to meet the heat demands of the particular towns.

The demand for heat from the power stations in each heat region is calculated as the total district heat demand ex plant minus the heat supply from industry and waste incineration.

3.1.6. District Heating

In the district heating module, Denmark is divided into two »district heating zones«: an urban zone consisting of all CHP-regions, having access to combined heat production, waste incineration, and industrial waste heat, and a rural zone consisting of all other district heating areas, where renewables and indigenous fuels are promoted.

Fig. 3.1. Load duration curves and production structure for the Danish power system by 2010. (Total power demand 40 TWh)



The district heating demand ex plant for each zone is defined as the sum of the heat demands for buildings and industries, corrected for transmission and distribution losses.

The maximum heat production for the various types of plants is calculated, and the heat demand is assigned to each type of plant according to a following priority list, which leaves fossil fuel-fired heat plants as residuals:

- Waste incineration with heat recovery
- Industrial waste heat
- Straw furnaces
- Other renewables
- CHP
- Natural gas boilers
- Oil-fired peak load plants
- coal-fired heat-only plants
- oil-fired heat-only plants

3.2. Environmental Effects of Danish Energy Policy

Since the mid-70s, there have been substantial environmental side-effects resulting from putting Danish energy policy into practice. The most important of these are:

- The switch from oil to coal for electricity production which was completed in the beginning of the 80s.
- Better building insulation and the heat planning, which has reduced the demand for primary energy for space heating, and changed its structure.

More recently, direct environmental protective regulations for reducing emissions of SO_2 and NO_x have been introduced.

3.2.1. Fuel Switch for Electricity Production

The switch from heavy fuel oil to coal for electricity production has reduced the emissions of SO_2 from power plants because of lower sulphur content in imported coal compared to the residual fuel oil which was used in the early 70s. This fuel switch was carried out by the power companies as a result of the increase of the oil price in 1973. In 1973 about 80% of the power production was based on oil. Ten years later the share of oil was reduced to less than 5%. Several oil-fired stations were converted to coal and all new power stations are coal-fired, or, more exactly, coal and oil fired, dual fuel plants.

The emissions are found in the DESS Model from the demand for fuels and the emission factors.

3.2.2. Structural Changes of the Space Heating System

The demand for space heating is reduced by insulation, changes in consumer behaviour, and increased heating efficiency. However, the heat planning which is now being realised may be more important for the reduction of primary fuel requirement and emissions from the space heating sector.

The Danish Act on Heat Supply, which was passed in 1979, regulates the operation of collective heat supply systems, i.e. district heating and natural gas systems, and contains a procedure for heat planning, which is an extension of the physical planning system that was developed during the 70s. This system is characterised by a very important role for local government. The main features of the heat planning has been the introduction of natural gas, expansion of district heating systems supplied by CHP and waste heat, and zoning of areas most suitable for natural gas, district heating, or individual heating according to criteria such as proximity to natural gas mains or power plants, building density, and the existence of a district heating grid.

Table 3.1 shows the planned changes in the space heating system. Although the total building floor area is expected to increase by nearly one-fourth, the primary energy requirement will decrease. The effects on the emissions are shown in Table 3.2, in which a situation in 2000 with no heat planning and no other abatement measures is compared with that of heat planning with no further abatement measures, and the planned situation in which abatement measures are assumed. The total SO_2 emissions will be reduced, and a much larger share will come from power stations with high stacks, which are better suited to the use of large-scale pollution abatement measures such as flue gas desulphurisation (FGD), leading to a further reduction in SO_2 emissions.

Tables 3.1 and 3.2 are typical examples of extracts of results from DESS Model calculations.

Table 3.1. Space heating structure in Denmark 1980 and 2000, PJ

	Useful energy		Primary fuel requirement	
	1980	2000	1980	2000
High stack				
Electrical heating, etc.	6	11	18	30
Combined heat and power	21	65	14	43
Medium high stack				
District heating plants, etc.	34	19	58	31
Waste incineration, etc.	4	15	6	23
Low stack				
Biomass and renewables	1	3	3	5
Private gas burners	2	19	4	26
Private oil burners	93	41	135	56
Total	161	173	238	214
Building floor area mill.m^2	303	372		

Table 3.2. SO_2 emissions from space heating in Denmark 1980 and 2000, 1000 t

Stack height	1980	2000 no measures	2000 heat planning	2000 planned FGD
High	32	35	54	22
Medium	74	85	24	12
Low	14	15	12	6
Total	120	135	90	40

3.2.3. Emission Reduction Regulations for SO_2

The Danish regulations for the reduction of SO_2 emissions are based on different principles for the power sector and for the rest of the energy system.

The Danish act on limitations of SO_2 pollution from power plants from 1984 is based on the principle that the Minister for the Environment shall set a limit on the maximum yearly amount of sulphur dioxide that may be emitted from Danish power plants. The limit has been set at 125,000 tons/year in 1995, and it will be further reduced in the following years according to a new act from 1988 based on the EC Council Directive on Large Combustion Installations, which also includes similar regulations for NO_x [7].

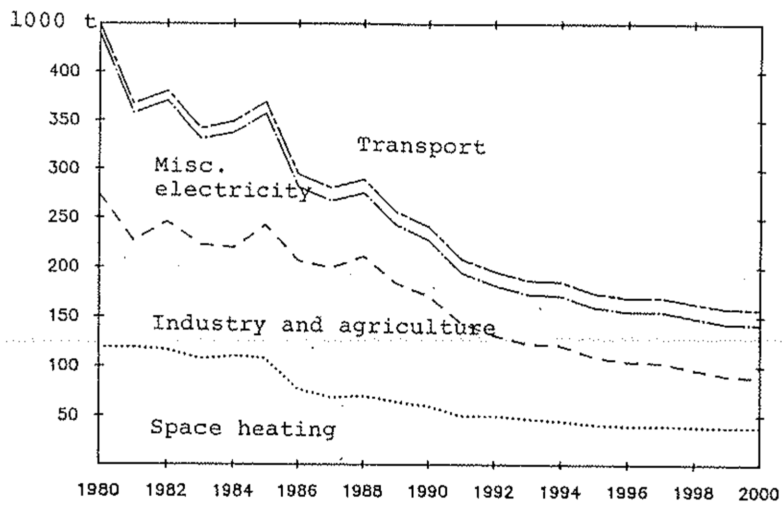
It is accordingly left to the two power companies between themselves to agree on the most economical way to achieve the emission reduction goals, but it has been agreed that in the coming years all new and some old Danish power plants will be equipped with flue gas desulphurisation. These power plants will be used as base load plants in order to utilise the investment in abatement facilities to the limit. This policy - often referred to as the »bubble policy« - is an alternative to stating emission standards for individual power plants, which is the basic principle in the German »Grossfeuerungsanlagen-verordning«.

In the industry and tertiary sectors, emission reduction regulations are not based on emission measurements but on reductions of the sulphur content in the fuel.

In the DESS Model, the power stations are divided into groups (maximum 9) according to abatement facilities as well as fuels, and the emission factors are reduced by the abatement efficiency. Outside the power sector, the emission factors are reduced according to the legal sulphur content. The effect of the implementation of the regulations is illustrated in Fig. 3.2 using the energy demand forecasts of the Status Report 1987 from the Ministry of Energy.

The legal limit for SO_2 from the power sector is not indicated in Fig. 3.2. To show this, the emissions must be divided into supply categories, which is easily done by the model. However, the DESS Model cannot accept the limit as a model constraint. This will require that an optimisation model be used, e.g. the EFOM model [8].

Fig. 3.2. SO_2 emissions 1980-2000



3.3. Germany

The DESS Model for the Federal Republic of Germany was implemented in collaboration with Professor Ulf Hansen, Lehrstuhl für Kraftwerkstechnik, Universität Essen. Under subcontract the software was installed and tested at the IBM 4341 computer at the Hochschulrechenzentrum at the University. A simplified database for the German power system was built up emphasising the structure of existing and potential combined heat and power for district heating, and the various modules of the model were implemented tentatively.

The model was further implemented and tested by Harry Pospischill for a study used as his diploma work. During this work, tests and recommendations were given by Risø using the recently established EARN Network (European Academic and Research Network) for transfer of data files (Pospischill 1987).

3.3.1. The Structure of the Power System

The model can treat 70 types of existing power stations and 30 types of new power stations each characterised by fuel type, efficiency, operating costs, and heat region for CHP. The model limits require that the power units be analysed and organised into a simplified structure.

The very diversified stock of power stations in the Federal Republic of Germany has thus been divided into some 20 groups taking into account the sizes, vintages, and emission abatement facilities of the power units. The basis for this simplified structure was the Kraftwerks-Databank at the University of Essen, which was built up in 1982 and updated continually since then. The results are illustrated in Table 3.3. The data for potential new units are based on the newest technology for the various types of units (see Table 3.4).

3.3.2. Load Variations of Power and Heat

In the study by Harry Pospischill, the electricity demand variation was described by load duration curves for four 3-month periods, while the heat demand is given as a constant for each time period.

3.3.3. CHP Regions

There are more than 50 urban areas in the Federal Republic with combined heat and power production and several others with a potential for that. For modelling purpose, the 6 urban areas with the largest volume of district heating are treated individually. These urban areas are West Berlin, Ruhrgebiet, Hamburg, Mannheim, München, and Wolfsburg. The district heating systems within these urban areas are not necessarily interconnected. There are, however, several plans for building transmission lines that connect separate district heating networks in the same urban area. The rest of the urban areas with CHP are grouped into types of areas according to their most important generating units: coal/extraction, coal/back-pressure, refuse, oil/back-pressure, large gas-turbines, and small gas-turbines.

As in Denmark the heat demand ex plant is calculated from the total heatdemand minus industrial excess heat (waste incineration has little significance). Outside the CHP regions there are some hundred district heating

Table 3.3. Model power stations in the German power system

Germany - Model data 20.08.87	Water	Pump Storage	Refuse	Lignt. 1955	Lignt. 60-70	Coal 1956	Coal 62-82	Oil 57-67	Oil 65-75	Gas 58-72
	Existing power stations									
Maximum power output, MWe	2500	3000	450	60	300	60	350	40	400	40
Max. power at max. heat output, MWe										
Maximum heat output, MJ/s										
Heat rate at condensing prod. MJ/kWh	3.6	5.4	23.7	11.7	10.5	11.3	10	14.7	9.2	11.7
Heat rate at back-pressure prod. MJ/kWh										
Basic fuel, TJ/a	0	0	900	120	600	120	700	80	800	80
Electricity/heat MW/MJ/s										
Electricity lost/heat MW/MJ/s										
Reliability	0.7	0.4	0.85	0.85	0.92	0.9	0.85	0.8	0.96	0.8
Availability	0.65	0.4	0.7	0.75	0.85	0.8	0.75	0.7	0.9	0.7
Operation and maintenance costs:										
Fixed DM/kW/a	100	50	120	120	81	84	57	65	53	56
Variable DM/MWh	2	1	7	8	10	7	9	3	7	2
Capacity 1980	2500	3000	450	600	9000	1800	26250	1400	16000	1600
1985	2500	3000	450	600	9000	1800	26250	1400	16000	1600
1990	2500	3000	450	600	9000	1800	26250	1400	16000	1600
1995	2500	3000	450	0	9000	0	26250	800	16000	1000
2000	2500	3000	450	0	6000	0	22750	400	16000	1000
2010	2500	3000	450	0	0	0	8750	0	10000	0

Germany - Model data 20.08.87	Gas 68-76	Nucl. 69-72	Nucl. 1977	LWR 75-87	Extrac. Coal	Extrac. Oil	Back-press. Coal	Back-press. Oil	Back-press. Gas	Refuse
	Existing power stations (cont'd)									
Maximum power output, MWe	400	650	850	1320	350	250	60	40	40	250
Max. power at max. heat output, MWe					229	180	60	40	40	178
Maximum heat output, MJ/s					440	346	140	93	93	342
Heat rate at condensing prod. MJ/kWh	8.7	10.8	10.6	10	9.85	9.2	13.83	13.83	13.83	23.7
Heat rate at back-pressure prod. MJ/kWh					4.353	4.08	4.27	4.27	4	4.35
Basic fuel, TJ/a	800	1300	1700	2640	700	500	120	80	80	500
Electricity/heat MW/MJ/s					0.52	0.52	0.43	0.43	0.43	0.52
Electricity lost/heat MW/MJ/s					0.15	0.15				0.15
Reliability	0.96	0.9	0.92	0.93	0.9	0.96	0.85	0.8	0.9	0.85
Availability	0.9	0.8	0.81	0.82	0.8	0.9	0.75	0.7	0.75	0.7
Operation and maintenance costs:										
Fixed DM/kW/a	31	90	78	68	57	53	84	65	90	120
Variable DM/MWh	3	1.5	1	1	9	7	7	3	10	7
Capacity 1980	12000	1651	3400	18480	2751	2050	2380	810	1570	600
1985	12000	1651	3400	18480	2751	2050	2380	810	1570	600
1990	12000	1651	3400	18480	2751	2050	2380	810	1570	600
1995	12000	1651	3400	18480	2751	2050	2320	810	1570	600
2000	12000	1651	3400	18480	2751	1250	1600	450	1570	600
2010	4000	0	3400	18480	1400	0	1150	400	1250	600

Table 3.4. New model power stations for Germany

Germany - Model data 20.08.87	Lignt. 600	Coal 700	Gas 400	Oil 40	LWR 1300	Ex-tract. (Danish data)	Back-press. (Danish data)
Maximum power output, MWe	600	700	400	40	1300	350	50
Max. power at max. heat output, MWe						252	50
Maximum heat output, MJ/s						434	125
Heat rate at condensing prod. MJ/kWh	10	9.4	8.5	11.7	10.7	9.7	14.9
Heat rate at back-pressure prod. MJ/kWh						4.35	4.33
Basic fuel, TJ/a	1200	1400	800	80	2600	700	100
Electricity/heat MW/MJ/s						0.58	0.4
Electricity lost/heat MW/MJ/s						0.15	
Reliability	0.95	0.94	0.96	0.85	0.93	0.94	0.85
Availability	0.88	0.85	0.9	0.75	0.82	0.05	0.75
Operation and maintenance costs:							
Fixed DM/kW/a	66	46	31	65	68	57	84
Variable DM/MWh	10	9	3	3	1	9	7
Investment costs	2350	1830	1500	200	3300	534	138

areas. In the proposed district heating module of the DESS Model for Germany, the 12 CHP areas are treated as district heating zone, and a 13th zone covering all other district heating areas is added [9].

3.3.4. Space Heating

The space heating demand for dwellings can be calculated like in Denmark as the product of projected building areas and unit demand. There are many studies of the future dwelling stock. The main source selected for this study is the detailed energy forecast carried out by Prognos in 1983 for the German Federal Ministry of Economics. For buildings other than dwellings, German statistics as well as statistics in most other countries and international statistics are nearly non-existent [10].

In contrast to Denmark, the split between space heating and domestic hot water is well documented, so the consequences of these two demands can be calculated separately in the model, if needed.

3.3.5. Other Sectors

For the other sectors of the German energy system, the DESS Model has been implemented tentatively using data and concepts from official statistics. This implementation was used to test the multinational application of the model, which is described in Chapter 4, below [11].

A considerable penetration of renewables is a more future option. Apart from conventional heat installations in buildings the most important existing type of smaller conversion units is industrial autoproducers of electricity.

Process and transport energy demand may be taken from the output of other models, e.g. the EFOM Model.

3.4. Italy

The implementation for Italy was included in the CEC study in order to test the DESS Model approach on a southern European country.

3.4.1. Implementation and Data Collection

The implementation of the model for Italy was made in collaboration with the two Italian institutions that take part in the EFOM Environment project: ENEA, Direzione Centrali Studi, Rome and Applicazione Ricerca Scientifiche (ARS) S.p.a., Milano. Seminars were held in Rome in July 1986 and June 1988 and at Risø in October 1988. Data was collected during a study tour to Milano and Rome in October 1987, which included visits to the Italian district heat association, Assoziazione Italiana Riscaldamento Urbane (AIRU) in Milano, as well as the statistical office, ISTAT, the national electricity company, Ente Nazionale per l'Energia Elettrica, ENEL, and ENEA, all in Rome.

The study of the implementation of the DESS Model for Italy is published as a separate report (Risø-M-2798) by Kirsten Halsnæs and Henrik Sørensen (1989). The focus of this study is on the following three topics: space heating, district heating, and the power system. The data collection for the study was finished early in 1988, and, thus, the decisions according to the new national energy plan were not taken into account.

3.4.2. Space Heating

There are very significant differences in the need for space heating in the different regions of Italy. In the Alpine regions of the north, the number of degree days is about the same as in Denmark or Germany, while the climate in the South is so mild that capital intensive heat installations may not be justified. In the DESS Model, the climatic differences are accounted for by dividing the country into three climatic zones.

3.4.3. District Heating

In North Italy, there are few district heating systems, but more systems are planned and further promoted by the national energy plans. The district heat module of the DESS Model includes detailed technical data about already established and planned district heating systems.

3.4.4. The Power System

The load-duration-curve, merit-order type power generation module of the DESS Model is devised for a system of thermal power plants. However, in Italy hydro power covered 22% of the demand in 1986, and electricity import 11%.

The essential problem of hydro power simulation is how to use a given time-dependent amount of water - representing a certain amount of potential power production - in the most efficient way. This means that the hydro power is to be used to replace the most expensive part of the thermal power production, i.e. the peak load. Hydro power plants are well suited for this because they can be started up in a few minutes, and because the production flexibility can be expanded by using pumping. In order to efficiently use hydro power, it is necessary to make a detailed forecast of the time-dependent amount of water that is at the disposal of each plant as well as its available storage and pumping facilities.

The power generating subsystem of the DESS Model allows the use of up to 12 load duration curves, one for each month. This feature has been used to simulate the Italian power system. Load duration curves for each month were calculated by subtracting the load from hydro power and net electricity import from the total demand in one-hour steps over a model period. This method is described and discussed in the report by Halsnæs and Sørensen (1989).

4. Multinational Applications

The flexibility of the DESS Model allows a great variety of applications as the examples of the previous chapter show. However, for a multinational application, a common set of definitions is needed along with common rules of model application.

4.1. The Eurostat Energy Balance

A practical way to meet this target is to utilise existing, well-established definitions. This leads to the idea of a multinational energy supply forecast model which is based on an international energy balance for the historical years. The more interesting items of this energy balance may then be broken down to elements consisting of conversion or end-use technologies or activities. Then forecasts are made by taking into account demand expectations and technology choices for an appropriate selection of these technologies.

The most obvious choice of energy balance for multinational studies for the European Community is the energy balance of Eurostat. A selection of this energy balance has been used as a frame for the type of national applications of the DESS Model that is described in Chapter 3. Within that frame, further harmonisation of the various sectors of the DESS Model can be made.

4.2. The Model Structure

The structure of this version of the DESS Model is illustrated in Table 4.1, using the elements of the DESS software system, »accounts« (vector series), »phases«, and print-out tables. The »accounts«, which are organised into vector series covering a subset of the energy system are explained in Table 4.2. The contents of the »phases« are listed in Table 4.3. There are two types of phases: »model phases« that contain the formulas for model calculations for the different energy sectors, and »data phases« that contain the input data. The former may be identical for several countries, while the latter consist of national specific data and modifications of calculation formulas.

The use of the Eurostat energy balance [12] as a frame for the DESS Model has been demonstrated using the modules that have been implemented for Germany. In practice, the published Eurostat energy balance for the base year (e.g. 1985) is imported into a spreadsheet and converted to DESS input format.

Table 4.1. Model structure for the DESS Eurostat Model.

	Vector series	Model phase	Data phases	Print-out tables
1 General data	E---	TOTA	DATA	
2 Buildings	BY--	BYGN	BDAT	BYGN
				BOLI
3 Renewables	VE--	ENKT	DVED	VEDV
4 Heat installations	IA--	IANL	DANL	IANL
				BINV
5 Process	PR--	PROC	PDAT	
6 Transport	TR--	TRNS	TDAT	
7 Power system with CHP	EL--	VERK	PROD	
			ELUP	DATT
		PRIS	EDAT	EINV
		- Power system simulation -		
		SIMU	PROG	SIMU
8 District heating	FV--	FJVA	FDAT	FJVA
9 Total energy system	C---	EBAL		STAT
		COST		COST

Table 4.2. Vector series for the DESS Eurostat Model

E---	Energy flows for 16 fuels from Eurostat energy balances
BY--	Building areas and unit heat demand for, e.g. 7 building types and, e.g. 3 building ages
VE--	Numbers of units, electricity and heat production capacities, efficiencies, other technical data, and prices for, e.g. 11 types of renewables.
IA--	Numbers of units, heat demands for single family houses and other buildings, efficiencies, other technical data, and prices for, e.g. 8 types of heat installations at various levels.
PR--	Process energy for, e.g. 5 industrial branches and, e.g. 4 fuel types.
TR--	Transport energy for, e.g. 4 types of transport and, e.g. 5 fuel types.
Power system (special format)	
	Technical data for max. 100 types of power stations.
	Max. 12 seasonal load duration curves.
EL--	Numbers of new and operating units, capacities, investment costs and pay rates for max. 30 types of power stations.
	Heat demands in max. 12 seasons for max. 25 CHP regions. Electricity demand for, e.g. consumer groups. Capacities, power production, fuel requirements, fuel and operating costs for max. 9 groups of power stations.
	Misc. technical data for the simulation of the power system.
FV--	District heat demand, heat plant capacities, and fuel requirements for, e.g. 2 types of regions and, e.g. 9 types of fuels.
C---	Fuel costs for 16 fuels from Eurostat energy balances.

Table 4.3. Model phases and print-out pages for the DESS Eurostat Model

Model phases	
PHASE TOTA:	Totals for the energy balance.
PHASE BYGN:	Building areas and useful heat demand. Number of dwellings and average heat demand.
PHASE ENKT:	Capacities, consumption, and production for renewables, etc.
PHASE IANL:	Small units: heat delivery, fuel requirement
PHASE PROC:	Final energy for industry, etc.
PHASE TRNS:	Final energy for transport.
PHASE VERK:	Power stations in operation year for year. Overnight investment costs for new stations.
PHASE DATT:	Forecast of electricity and heat demands.
PHASE SIMU:	Thermal electricity demand Simulation of power system.
PHASE PRIS:	Annual investment costs for new power stations.
PHASE FJVA:	Fuel demand for district heating.
PHASE EBAL:	Calculation of the future energy balance.
PHASE COST:	Calculation of fuel costs.
Data phases	
Power syst.:	Production data for power stations.
PHASE DATA:	Initial energy balance from Eurostat.
PHASE BDAT:	Unit heat demand and building areas.
PHASE DVED:	Data for renewables.
PHASE DANL:	Data for small units.
PHASE PDAT:	Data for process and transport.
PHASE ELUP:	Development plan for power stations. Investment costs etc. for power stations.
PHASE PROG:	Prices, efficiencies, etc. Heat demand in heat regions Electricity demand forecasts.
PHASE FDAT:	Data for district heating demand and preferred fuel and interface to preceding modules.
Print-out pages	
PAGE BYGN:	Unit heat demand and building areas. Useful heat demand. Number of dwellings.
PAGE VEDV:	Technical data and production of renewables.
PAGE IANL:	Number of individual heat installations, heat, hot water, and cooking demand from individual installations, fuel requirements and costs.
PAGE DATT:	Forecast of electricity and CHP demands, and fuel prices for power production.
Power syst.:	Detailed simulation results.
PAGE SIMU:	Capacities, production, costs and fuel requirements of thermal power stations. Simulation of power system.
PAGE FJVA:	District heating supply, fuel requirements and costs.
PAGE FUEL:	Fuel prices, fuel requirements, and costs.
PAGE COST:	Fuel costs in Eurostat categories.

5. The DESS and EFOM Models

The Energy Flow Optimisation Model (EFOM) is a tool for analysing long-term investment strategies, while DESS is a tool for analysing the consequences of technology choices or investment plans.

Like the DESS Model, the energy supply system is described in the EFOM Model as a network of energy conversion and transport facilities [13]. However, instead of a simulation based on forecasts of technology choices and capacity developments, a linear programming problem is set up and solved in order to disclose an optimal solution for the sequence of investment in energy conversion and end-use technologies as well as emission abatement measures.

The present software of EFOM Model uses a very purpose-specific database. Thus, the preparation of data for these models will demand some kind of preprocessing of national specific data. As a more general database, the DESS Model is well suited to this purpose.

5.1. The Energy 2000 Study

The EFOM model is the supply part of the Commission's energy model complex, which has been used since the 70s. It was implemented by Risø for Denmark at that time, but the model was never used for national energy planning, and was therefore not fully updated for the Energy 2000 study [14].

5.2. The Energy and Environment Study

The extension of the model that includes emissions of pollutants and emission abatement techniques was developed by three German institutes during 1986 and 1987 as a part of the research project »Optimal Control Strategies for Reducing Emissions from Energy Production and Energy Use on an European Level« [15]. This extended model has now been implemented for all EC countries, and various scenarios for the reduction of pollutants – in particular, SO_2 and NO_x – are being studied.

5.3. CHP from the Central Electricity System

Combined heat and power (CHP) for district heating is a very important feature of the Danish energy system. According to the national heat planning, the share of CHP for space heating is to be expanded to about 45% by the late 90s. CHP is produced mainly by large extraction-condensing power plants, which are a part of the central electricity system. An important weakness of the earlier implementations of the EFOM Model for Denmark had been that this feature could not be properly described by the model.

This problem was solved during the implementation of EFOM for the »Energy and Environment« study by inserting a link from the central electricity subsystem to the urban combined subsystem; this converts potential electricity production into piped hot water for district heating. According to the technical data of modern extraction-condensing power plants, the extraction of one unit of heat energy means giving up 0.15-0.20 units of electricity (German: Stromverlustkennzahl - or the parameter c_v, explained in Grohnheit 1986a).

5.4. Data Selection and Transfer

The general economic and technical data for the Danish implementation of the EFOM Model were taken over from the multinational version of the model as far as possible, and special national data were used for only very important technologies, where Danish experience differs from the multinational data, or where no technical data were available.

The national specific data for energy flows and capacities were taken from the official statistics and the version of the DESS Model that was used for the Status Report on Energy Planning 1987 from the Ministry of Energy as well as results from the Energy 2000 study. The forecasts from the two studies were analysed and compared using a Lotus 1-2-3 spreadsheet in order to compile the Danish forecasts for the EFOM Model. The selected forecasts were compiled on the spreadsheet in a DESS format and transferred to the EFOM database using a small program on the VAX written in Pascal.

The historical data for the energy flows were based on the national sources, while the forecasts were compiled using the growth rates found in the data from the Energy 2000 study. There were, however, various differences and inconsistencies between the national definitions used for energy statistics and the definitions used for international statistics, e.g. Eurostat, or those used for the Energy 2000 study.

The data for existing and planned capacities of energy conversion technologies etc. were taken from official statistics, the DESS Model results for the Status Report 1987, or calculated on the basis of the energy flow data and appropriate technical data.

5.5. Results

The main results of this study were that the SO_2 reduction targets of the Danish legislation and the EC Directive will be easily achieved, mainly by introducing new clean technologies in the power sector. Only more tight SO_2 emission limits will require widespread use of abatement technologies.

On the other hand, the model version used for this study does not give a feasible solution for more than a 35% reduction of NOx compared with the 1980-level, and this target will be achieved only by widespread use of abatement technologies.

Although the scenario assumptions for this multinational study are not identical to those used for the official Danish energy planning, the scenario results tend to confirm the cost-efficiency of the overall energy-planning targets. However, the most interesting result of the scenarios may be that the model prefers new »clean« technologies for power generation (e.g. integrated gasification combined-cycle power plants) instead of conventional coal-fired power plants with flue-gas treatment for SO_2 and NO_x.

6. The Power System with CHP

The power system with CHP from thermal power stations is the most elaborate part of the DESS Model, and it can be described properly in the EFOM Model as well. The power system is the most important part of the energy system, and it is the subject of a wide range of systems analysis models. Cogeneration of heat and power for district heating of buildings is the single technology which offers the largest potential for a substantial reduction of the primary fuel requirement in the temperate climatic zones.

As described in Section 3.2, the extensive use of CHP in Denmark has led to a substantial reduction of emissions from space heating. Projects for combined heat and power for district heating in urban areas have been carried out in several cities, in particular in Denmark and Germany, and several studies have been made in other EC countries, e.g. in the United Kingdom.

6.1. CHP Schemes in the United Kingdom

No major CHP scheme has yet been implemented in the UK. This is in spite of many detailed studies and sustained interest from local authorities and the House of Commons Select Committee on Energy, Lead City Schemes, as well as the Energy Act of 1983, which removed legal barriers. The Department of Energy has published three Energy Papers on Combined Heat and Power and District Heating in the UK between 1977 and 1982 [16].

Physical factors such as dwelling densities, climate, and heating systems may explain why the penetration of district heating in the UK is lower than in the other countries. The United Kingdom has a relatively mild winter climate, so that the peak heating requirement is lower in London than, for example, Stockholm.

> »This factor is well known and often quoted as one favouring district heating in colder climate. It is not always recognised, however, that more severe winter conditions result in lower load factor (...) and this tends to cancel out the above climatic effect.«

The most important factor in explaining the absence of district heating in the UK is probably the institutional arrangements:

> »It is common in European countries for one organisation, often controlled by a local authority, to be responsible for gas and electricity supply and district heating. Integration of local planning and energy distribution is thus facilitated, and it is possible to designate high housing density areas for district heating, intermediate density areas for gas, and low density areas for electric space heating, This is contrast to United Kingdom context, where energy supply is the responsibility of separate national bodies, and there is a wide range of consumer choice particularly with privately owned houses« (Energy Paper 20. p. 19-20)«

In Energy Paper 35 (1979) the majority of the Combined Heat and Power Group recommended that one or more lead city schemes of CHP should be started as soon as practicable. The most important key points for this recommendation were:

> »When oil and natural gas are no longer available for heating, the potential for CHP/DH could possibly be in the region of 30 per cent of the existing domestic, commercial and institutional heat load in the UK. ...

> »We cannot emphasise too strongly that a prerequisite of having CHP/DH in the future is to develop district heating networks in the meantime. This means making a start with heat-only boiler schemes (and

perhaps small sized CHP plant) so that they can be connected up to medium or large CHP plant at a later stage.

»In the short term, CHP cannot be expected to take off on its own accord on any scale, largely because of the competition from other fuels, particulary gas. However if nothing is done, we shall not, because of the long lead times, have a CHP option when we need it.«

Natural gas supply is well established in the UK, covering some 60% of the heat market. Virtually all areas suitable for CHP are connected to the gas system, providing a clean, convenient, and well-known source of heat supply. The consumer, therefore, has little incentive to prefer CHP to gas.

One of the most advantageous potential CHP areas described in Energy Papers 53 is the London Boroughs of Tower Hamlets and Southwark. The London Docklands, where a huge redevelopment is now taking place as an extension of the City's office space, is in the middle of this area. The opportunity to supply this area with CHP was not mentioned in the report. A development corporation independent of the local authorities has been set up for planning and coordinating the development of the area. The heat and electricity demand of the area may eventually take most of the output from a large power plant.

6.2. A Dynamic Model Approach for CHP

An economic assessment for these CHP schemes may show that they are economically attractive in the long run. However, there is no incentive for any potential decision-making body in the short run.

Such results may be used as an argument for legislation, planning implementation for central or local authorities, or government subsidies. They do not, however, provide the decision-making body with information on the expected profitability of the system during a transition period of many years, which is likely to involve unpredictable changes in essential parameters, e.g. energy prices. To achieve this, a dynamic model approach will be required in order to investigate a wide range of technology choices, forecast assumptions, and investment sequences.

6.2.1. A Common Model Structure for DESS and EFOM

Both the DESS and EFOM Models are well suited to studies of the electricity sector.

In the DESS Model, the capacity of each technology is exogenous. In the EFOM Model, a linear programming problem is set up and solved in order to disclose an optimal solution for the sequence of investment in energy conversion and end-use technologies as well as emission abatement measures.

A flow-chart of a subsystem of the EFOM Model is shown in Fig. 6.1. This example refers to the situation in densely built-up urban areas in the United Kingdom, but it may apply to other countries as well.

URBAN HEAT SUBSYSTEM FOR THE DESS AND EFOM MODELS

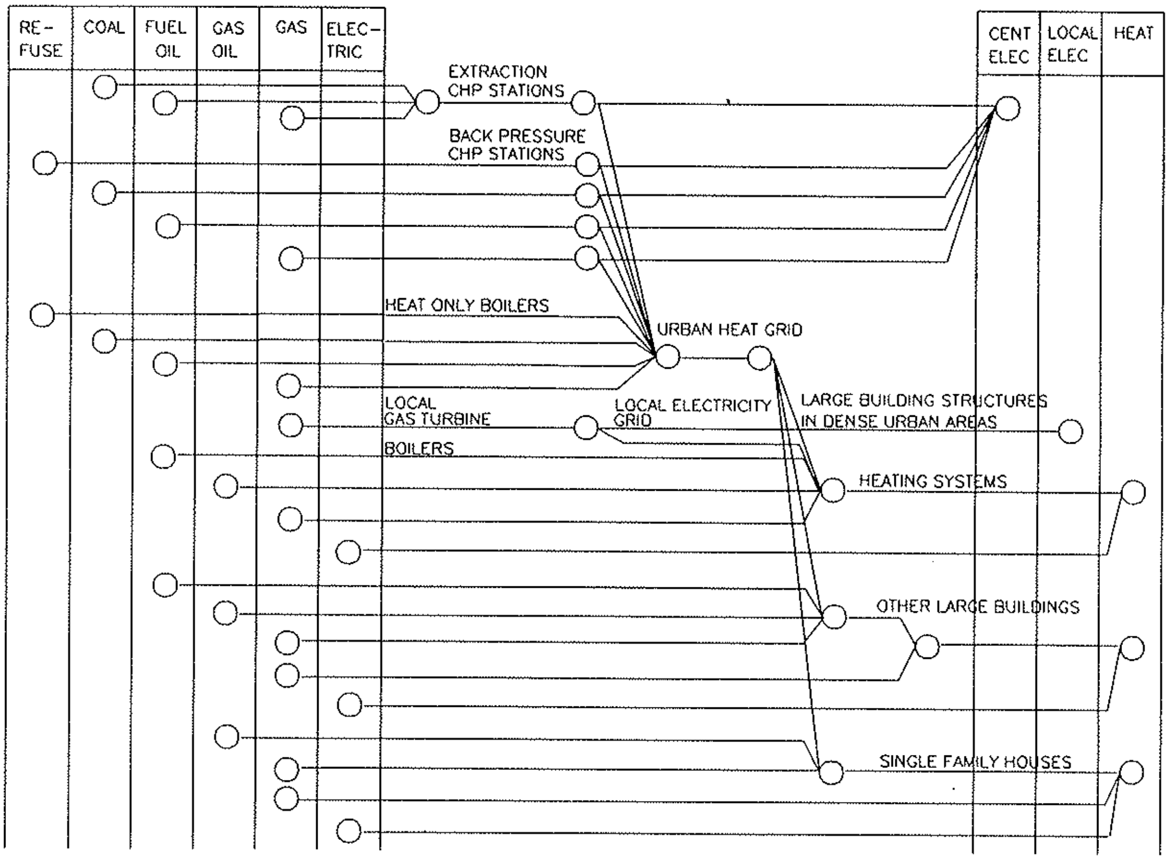


Fig. 6.1 Proposal for an urban heat subsystem for the DESS or EFOM Models.

6.2.2. The Heat Demand Structure

Buildings in potential CHP areas are divided into three groups:

- Large building structures (e.g. high-rise office buildings) in densely built urban areas subject to further increase in heat density and electricity demand.
- Larger buildings (e.g. multi-family houses) outside very dense urban areas.
- Single-family houses.

6.2.3. Heat Supply Technologies

The heat supply options to be included in the urban heat subsystem of the model are:

- Single-family houses: room heating with gas or electricity; water-based heating systems with boilers fired by gasoil or natural gas; or district heating.
- Larger buildings: room heating with electricity; water-based heating system with gas-fired boilers in each dwelling unit; central boiler fired by natural gas, gas or fuel oil; or district heating.

- Large structures in dense urban areas: all-electric system for heating cooling and ventilation; integrated system supplied by a central boiler, or gas turbine for CHP; or district heating.

6.2.4. Power Stations

The following types of power stations are assigned to each CHP area:

- Large extraction-condensing power stations, 200-400 MWe, located within the urban region. These stations are part of a national system of large power stations. The co-produced heat is transmitted to the consumer over 20-40 km. The total efficiency when cogenerating is about 80%. The extraction of heat will reduce the electricity load by 15-25% of the amount of heat. These stations are fired by coal, heavy fuel oil, or natural gas.
- Back-pressure power stations of various types and fuel supply, up to 150 MWe. The fuels are refuse, coal, fuel oil, or natural gas. The output of these stations is a mix of electricity and heat in a fixed proportion. These stations are located within or close to the urban area. The electricity is delivered to the national grid, and the heat is delivered through urban transmission mains.
- Gas turbines, as described above, integrated in the heating system of large building structures, supplying heat and electricity for local use.

Electricity-only power stations for the national grid may be found in another subsystem of the EFOM Model. For the DESS Model, all power stations in the national grid may be included in the simulation of economic dispatch. However, for a separate study of an urban heat system, only an appropriate selection of condensing power stations is necessary, representing, e.g. nuclear, lignite, coal, oil, and peak-load units.

6.2.5. CHP Areas

The urban heat subsystem described for the EFOM Model does not allow for a geographical separation of district heating grids. In the DESS Model, on the other hand, it is possible to define up to 25 CHP areas, to which heat demands as well as power stations or other heat-producing installations may be assigned.

6.2.6. Technical and Economic Data

Each technology is described by various technical and economic parameters. For the EFOM Model, the number of technologies should be restricted to those described in the urban heat subsystem, and aggregate parameters must be used. In the DESS Model, more than one version of the same technology may be included, especially for power stations.

6.2.7. Scenario Data

The necessary scenario data for both models are forecasts for energy demands and energy prices, and initial data for capacities. For the DESS Model, planning data for capacity development is also included. For the EFOM Model, some planning data may be given to restrict the choice for the optimisation.

6.2.8. Model Runs

The urban heat subsystem for the EFOM Model may be run separately or together with subsystems for other parts of the energy system. The model is run as a linear programming problem seeking an optimal solution with minimum costs subject to a number of constraints. These constraints may be physical, economic, or environmental, e.g. 30% reduction of SO_2 emissions from 1980 to 1995.

The simulation by the DESS Model is made sequentially in the following order:

1) Electricity demand for heating is added to electricity demand for other purposes.
2) The heat demand to be supplied by CHP in each CHP area is calculated from total heat demand, merit heat supply (e.g. waste incineration and industrial excess heat), and grid availability.
3) The electricity and CHP simulation submodel is run and the fuel requirements are found.
4) The remaining district heat demand is supplied in the following merit order: coal, fuel oil, natural gas, gas oil.
5) Fuel, investment, and operating costs are calculated.
6) Emissions of pollutants are calculated.

6.3. CHP in Densely Built Urban Areas

The optimal type of a CHP/DH scheme for a middle-size or big city is in most cases supply of heat from a fairly large nearby power plant to cover a large part of its heat demand. If such a scheme were to start from scratch, it would very likely be unable to meet the investment criteria, in particular those required for a corporation or an authority with a short time horizon. Some infrastructure must be available, or some government subsidies must be given if the large threshold investments for CHP are to be carried through.

The size of the large building structures, which are common in many large urban areas, may justify the installation of gas turbines for cogeneration of heat and electricity, either for a single huge building structure or a few nearby buildings. The costs per MW electric for reasonably large gas turbines is substantially lower than those of large coal-fired power plants. Their location are often in areas with an increasing demand for electricity, so replacing them with local gas turbines may reduce the need for investment in increased capacity for the electric grid. The gas turbines may supply electricity at peak demand, while the less time-dependent heat demand can be met by a relatively cheap water storage.

When fuel prices are low, the absolute difference between coal and gas prices are small, so savings in investment for central power stations and electricity grids would not be offset by higher fuel costs. When fuel prices are high, however, the price difference between coal and gas may justify investment in heat transmission mains and new coal-fired extraction-condensing power plants for base load. This would be especially true if the local infrastructure is suited to a more centralised CHP/DH system.

The scheduled subsystems of the two models are planned to enable this kind of dynamics to be analysed.

7. Conclusion

A simulation model, such as DESS, can be formulated and run more easily than an optimisation model, which must comply to some more elaborate mathematical and programming tools. This allows greater flexibility in the problem formulation and a more detailed system description. On the other hand, the simulation model requires more exogenous data.

A linear optimisation model for the energy system, such as EFOM, is able to give some answers concerning technology choices and investment profiles on the basis of relatively few selected constraints. However, it may not produce a balanced and credible forecast of the development of the energy system. When optimising, the model will tend to select some extreme development: one technology will tend to be the optimal choice under a given set of assumptions, and if these assumptions are changed, another technology may be preferred.

Thus, an optimisation model is rather unlikely to produce a balanced and credible development path of the energy system. This will most often require a balanced mix of technologies that takes into account the uncertainties of the real world and all the conflicting objectives which cannot be formulated quantitatively, even if the mathematical model were itself large and elaborate.

To some extent, this problem is solved by introducing more constraints into the optimisation model, but if too many constraints are introduced, the idea of an optimisation model vanishes. Only a »simulation« model remains, which is unnecessary complicated mathematically, and no real optimisation will take place. The art of modelling is to choose the model that fits the need.

The »Energy and Environment« study has demonstrated the value of the optimisation model, in particular for the power sector. Different restrictions will give different model results for the optimal technology choices. This may not produce a forecast for the development of the energy system, but it will point out those elements that might be included in forecasts for investments, fuel requirements, and energy system costs.

These features may be modelled using a simulation concept like DESS. For the energy system as a whole, it is necessary that this forecast be based on a well-established statistical tool such as the energy balance, as scheduled in Chapter 4.

For the power system alone, the relatively small number of available technologies may allow more room for making conclusions that are based on results from the EFOM Model. However, the DESS Model offers the opportunity for far more detailed results concerning plant sizes and geographical distribution.

It would be unwise to make conclusions that are too general concerning the computer software for the DESS modelling concept. Modern commercial spreadsheet software has already taken over many of the calculations that were previously made by the special-purpose FORTRAN software, except for the power system submodel. However, it is time-consuming to transfer an existing model to a more modern »user-friendly« tool, and these tools for personal computers have practical limits. When implemented, the existing DESS software can handle a large amount of data and calculations very quickly on a mainframe computer.

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The DESS (Detailed Energy System Simulation) Model is a tool for translating energy demand forecasts into their economic and environmental consequences. This model, which has been used for the Danish national energy planning, was developed and extended within the energy modelling program of the Commission of the European Communities into one that is able to simulate different national energy supply systems, in particular the power generating and space heating sectors. The model has now been implemented for Denmark, Germany, and Italy. The model implementation is described in this report, and further applications of the model is discussed. These include: national or multinational database and simulation model for the energy system, database and preprocessor for optimisation models, and sectoral models, in particular for the power system with combined heat and power (CHP). Finally, the use of simulation models and optimisation models, e.g. the Energy Flow Optimisation (EFOM) model, is discussed.

Descriptors INIS/EDB

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